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FABRICATION OF A SEALED OFF CO2 GAS LASER

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FABRICATION OF A SEALED OFF CO_2 GAS LASER

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

To my beloved parents, wife and sisters.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of requirement for the degree of Master of Science

FABRICATION OF A SEALED OFF CO_2 GAS LASER

By

SHAHID IQBAL

August 2002

Chairman : Nasrullah Khan, Ph.D.

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This study consists of two parts. In the first part a mathematical model for sealed-off CW CO_2 laser is developed. The developed model based on the four-temperature model and is developed by modifying the steady state CO_2 laser model presented by Scott et al. [28]. The equations relating the modes energy verses intra cavity optical intensity in equilibrium are used for modelling. An energy balance equation involving the terms of power loading, optical power removed and power loss in the form of the heat removed through the laser tube walls is derived. The variation in the output power as the power loading is varied is predicted using the model. The predicted results of output power respective to the power loading are found to show the similar response as found experimentally.

In second part a sealed off CO_2 laser is fabricated using custom-made air-cooled laser tube with internal mirror design and power supply. Both laser tube and power supply are placed in custom made wooden box. The box is especially built for housing the laser components. The cooling of the laser tube and power supply is

achieved by using four fans. An electronic circuitry to measure the laser tube temperature is developed. The laser is operated both in continuous wave mode as well as in pulse mode. A maximum power of 12.2 Watts is measured during continuous wave mode operation at a current of 14 mA. The output power is found to decrease with further increase in current. During pulsed operation, the energy of the optical pulses is found to be maximum at 100 Hz and a decrease in the pulse energy is detected with further increase in the pulse repetition rate.

The temperature is found to be the major factor effecting the laser power. Without fans the temperature of the laser tube is found to reach to $85\,^{\circ}C$ in 10 minutes. The output power is also found to drop to zero at $85\,^{\circ}C$. However with running fans, the maximum temperature that laser tube wall could reach is found to be $55\,^{\circ}C$ independent of the time. The laser power at $55\,^{\circ}C$ is found to be 9 Watts.

The threshold and steady state voltage at the laser tube electrodes is also measured and is found to be 15640 volts and 8160 volts respectively. The CO_2 laser is useful for industrial drilling, welding, cutting and for air ionization or discharge applications. The purpose of this research is to design 14 Watt CO_2 gas laser for air ionisation and high voltage sphere gap triggering in the subsequent research.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

FABRIKASI PENUTUPAN LASER GAS CO_2

Oleh

SHAHID IQBAL

August 2002

Pengerusi : Nasrullah Khan, Ph.D.

Fakulti : Kejuruteraan

Kajian ini merangkumi dua peringkat utama. Pada peringkat pertama model mathematik utk sealed off CW CO_2 telah dihasilkan. Model ini berasakan kepada model 4 suhu disamping menggunakan beberapa persamaan yang menghubungkan mode tenaga berlawanan dengan keamatan optikal di dalam cavity. Persamaan keseimbangan tenaga yg melibatkan aspek kuasa muatan, pengasingan kuasa optikal dan kehilangan kuasa dalam bentuk haba melalui dinding tiub juga telah di dibuktikan . Perubahan pada kuasa yg dikeluarkan di samping kuasa muatan dpt ditentukan menggunakan model ini. Hasilnya, kuasa output yg dijangkakan berdasarkan kuasa mutan didapti menunjukkan kesamaan tidakbalas sebagaimana yg di dapati melalui ekseperimen.

Pada peringkat kedua, laser sealed off CO_2 telah dihasilkan menggunakan tiub laser khas yg mempunyai sistem penyejukan udara dengan binaan cermin dan sistem bekalan kuasa dalaman. Kedua-dua tiub laser dan sistem bekalan kuasa di letakkan di dalam kotak kayu khas. Kotak ini di buat khas sebagai pelindung kepada komponen laser. Sistem penyejukan utk tiub laser dan sistem bekalan kuasa dihasilkan

menggunanakan empat buah kipas. Litar elektronik utk mengukur suhu tiub laser juga telah direka. Laser ini beroperasi dalam dua bentuk mode, mode gelombang berterusan iaitu pada penggunaan arus sebanyak 14 mA. Kuasa output pula didapati menurun dengan pertambahan kadar ulangan pulse.

Suhu adalah factor utama pada perubahan kuasa laser. Dalam keadaan dimana kipas tidak digunakan, suhu laser itu didapati menjangkau $85^{\circ}C$ dalam masa 10 minit. Walaubagaimanapun, kuasa output jatuh kepada sifar pada suhu ini. Sebaliknya, dengan penggunaan kipas suhu maxima dinding tiub laser hanyalah menjangkau $55^{\circ}C$ dan ianya tidak dipengaruhi oleh masa. Kuasa laser pada suhu ini adalah 9 Watt dan ianya juga tidak bergantung pada masa.

Voltan threshold pada elektrod tiub laser juga dapat diukur iaitu 15640 volt, manakala peringkat stabil voltan pula pada 8610 volt. Laser CO_2 berguna kepada industri penggerudian, pengimpalan dan pemotongan dan juga berguna kepada pengionan udara atau aplikasi-aplikasi menyahcas. Tujuan penyelidikan ini ialah untuk merekabentuk laser gas CO_2 untuk digunakan di dalam ekperimen pengionan udara dan voltan pencetus tinggi berjarak sfera di dalam penyelidikan seterusnya.

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I certify that an Examination Committee met on 13th August 2002 to conduct the final examination of Shahid Iqbal on his Master of Science thesis entitled "Fabrication of a Sealed off CO_2 Gas Laser" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follow:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

SHAHID IQBAL

Date: 18-11-2002

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LIST OF ABBREVIATIONS

CW	Continuous Wave
CO_2	Carbon Dioxide
FIR	Far – infrared
N_{CO_2}	Number of Molecules of Carbon
N_{N_2}	Number of Molecules of Nitrogen
X_i	Rate of Energy Transfer to the Four Vibrational modes of CO_2
hf_i	Energies of Vibrational Modes of CO_2
N_e	Number of Electrons per unit Volume
I_υ	Intra-cavity Optical Intensity
h	Planks Constant
f_L	Laser Frequency
τ_c	Life time of Photon inside the Cavity
W	Stimulated Emission on line Center
S	Spontaneous Emission
c	Velocity of Light
HV	High Voltage
VM	Voltmeter
N	Fresenel Number
LED	Light Emitting Diode
DPDT	Double Pole Double Through

CHAPTER 1

INTRODUCTION

1.1 Introduction

The word "laser" stands for "Light amplification by stimulated emission of radiation". The stimulated emission is the process in which a photon of energy $h\upsilon$, stimulates the electron of an excited atom, to make transition from higher energy level to lower energy level, yielding another photon of same wavelength, same polarization, in phase and in same direction [1]. The process of stimulated emission is illustrated in the Figure 1.1.

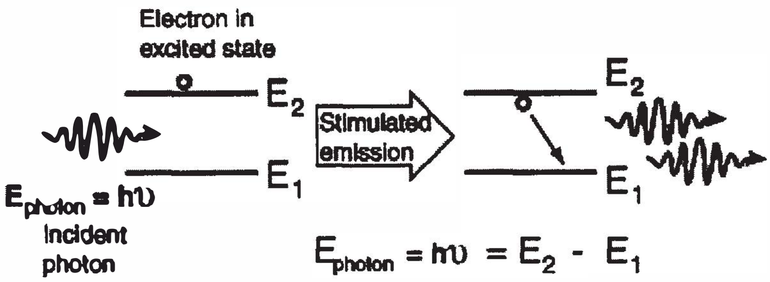

Figure 1.1: Stimulated emission process

Many types of lasers have been designed since their discovery in 1961. However the CO_2 laser was first time discovered by Patel in Bell Laboratories in 1964 [1,2]. The CO_2 laser uses carbon dioxide gas as active medium and like other gas lasers it consumes electrical power and deliver less power in its radiation form at about $10.6\mu m$ wavelength. The difference between input and output power is waste heat that must be consumed. It operates by exchanging energy between low-lying vibrational-rotational energy level of CO_2 molecule. The radiation field transfers molecule being in the higher energy state into vibrational energy mode with lower-energy state. The difference of energy between upper and lower energy state is converted into far-infrared radiation [3].

The stimulated emission in CO_2 laser is different in the sense that it is due molecular transitions (vibrational-rotational transitions of molecules). The CO_2 laser has high efficiency and power output as compared to other lasers. The CO_2 lasers are of many types e.g. sealed off, flowing gas, axially excited, transversely excited etc. The maximum output power of a CO_2 laser is limited only by the damage threshold values of transmitting and reflecting optical components. A power output of 40kW in case CW CO_2 laser and 100MW from pulsed CO_2 laser has becomes possible with today's technology. The wavelength of CO_2 laser light is $10.6\,\mu m$, which falls in far-infrared region of the electromagnetic spectrum and is referred as thermal radiations. This radiation can be focused on a diameter of $10.6\,\mu m$. So the CO_2 laser makes it possible to concentrate high heat radiation on the exact point [2].

The CO_2 lasers have many applications depending upon the output power. The high power CO_2 lasers are widely used in industry for various purposes e.g. for material processing and for laser hardening. The CO_2 lasers are used for cutting and welding of metals. Steel plates of several centimetres thick can be cut very easily with 10kW CO_2 laser. The high-energy short pulses are used for the fusion confinement. It has many applications in medicine e.g. operation of high blood organs, reduction of bleeding and neurosurgery [3].

The earth atmosphere has low-loss optical window for the wavelength ranges between $8\mu m$ to $14\mu m$ [2]. Thus the high, efficiency, output power of CO_2 lasers and less retardation of earth atmosphere at $10.6\mu m$, makes the CO_2 laser most suitable for earth atmosphere ionisation experiment. Hence the design is carried out to use the laser for the ionisation experiment. However the intended design of sealed off CO_2 laser has been selected and carried out, because of its more compactness, easy to operate, less expensive, and its ability to render more stable output spectrum and power than other CO_2 laser types.

1.2 Aims and Objectives

Aim of this project is to develop a mathematical model for sealed off CW CO_2 laser and fabricate CO_2 gas laser. The fabrication is aimed to get 14-Watt output power in CW mode and high-energy short duration pulses in the pulsed operational mode. The laser yields such an output power at $10.6\mu m$ wavelength range. This wavelength falls in far-infrared (FIR) region of electromagnetic spectrum.

The main objective of this research are,

- to develop mathematical model for sealed off CO_2 gas laser
- to fabricate a sealed-off CO_2 laser and
- to operate the laser both in CW and pulsed mode.

1.3 Scope of Work

A mathematical model for the sealed off CW CO_2 laser is developed. The output power as a function of discharge current is determined for an arbitrary sealed off CW CO_2 laser. The maximum power of fabricated laser is measured to be 12.2 Watts at 14 mA. The further increase in current results in the decrease of power. The energy of output optical pulses is measure as a function of pulse repetition rate. The energy of the optical pulses is found to be maximum at 100 Hz. The output power as function of wall temperature is determined and it is found that the power dropped to zero at $85\,^{\circ}C$. The threshold and steady state voltage is also measure. The burning and cutting effects of the laser beam have also been analysed. It has been found that the laser beam can cut very easily the half centimetre thick plastic and wooden sheets.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter comprises the literature review, theory of lasing action in CO_2 gas, the factors effecting the scaling of the output power and the methods to overcome. The design criteria of sealed off CO_2 has also been described briefly.

2.2 Literature Review on CO_2 Laser

The lasing action in CO_2 gas discharge was first time reported by Patel in 1964. The output power of this first reported CO_2 laser was around 1 MW. The laser was CW type [4]. However, within a year, CO_2 laser output powers had reached 10W, with an efficiency of 10%, while in 1967, CW operation at 500W was achieved. The subsequent substantial increase in CO_2 laser output power was made possible by cooling the active mixture convectively. A CO_2 laser with effective gas cooling by transverse circulation has produced an output power of around 1kW in 1969 [5]. There are many different types of design for CO_2 laser, which generally can be divided into three different groups on the basis of gas flowing as, fast flow, slow flow and sealed-off laser systems.

For a fast flow system, mass transfer or the flowing gas removes the heat produced by the electric discharge. The output power is largely dependent on the mass flow rate (amount of laser gas medium flow per second) of the gas, which can be as high as 120 to 150W of output power for each gram per second of mass flow [3]. The fast flow system can be divided into two major types as the fast-axial-flow and fast-transverse-flow system. The fast axial flow laser is the one in which the optical axes, current and gas flow are in the same direction. Since the discharge length for gas molecule to traverse is relatively long in the axial direction, the gas flow velocity must be relatively high in order to minimize the transit time. A high flow velocity means high pressure-drop, which in turn requires more power for driving the gas pumping system. Roots type gas pumps are usually used in these lasers. Discharge currents are perpendicular to the optical axis. In this system, a lower flow velocity is needed remove the discharge heat. These fans used are simpler, consume less power and are more reliable when compared with the roots pumps used in fast axial flow lasers.

The slow flow types of lasers are reliable, robust, and easy to operate, and are produced by the industry in many versions with powers ranging from tens of watts to a kilowatt. The heat generated by the electrical discharge is removed by heat conduction through a water jacket surrounding the laser discharge tube. To continuously refresh the mixture, the gas is slowly pumped through the tube.

A sealed-off CO_2 laser offers convenient application because there are no vacuum pumps and gas bottles needed. The cooling of this laser is the same as in the conventional slow flow type by the enclosing water jackets. The output power of sealed-off CO_2 lasers can only increased be by increasing the discharge tube length. The one major problem associated with sealed-off CO_2 is their short operating lifetime, which is of the order of several thousand hours [3]. From the invention of the CO_2 laser onwards, research has been carried out to decrease the dissociation of the laser gas and its interactions with surface of the materials in order to find appropriate conditions for a sealed-off laser.

Witteman [6] designed a sealed off CO_2 laser by using ordinary materials for the tube and electrodes. A decrease in output power was found with passage of time. It was supposed that either some of the gas components were absorbed or impurities released during the discharge. The materials used for the laser tube and electrodes and also the shape of the electrodes were found to have important role. Water vapours were added to the gas mixture, which reduced the problem to much extent.

Fahlen [7] designed a 5-W CW CO_2 laser and developed an expression for the small signal gain of the sealed off CO_2 laser given as

$$g_{\circ} = 0.012 - 0.0025 D_T cm^{-1}$$

An increase in optimum output coupling (%) with the increase in single pass gain was found. The methods to calculate the output power of the sealed off CO_2 laser was described. Graphical representation of relation between the diffraction losses and the Fresnel Number was presented.

Macken et al. [8] designed a sealed off CO_2 laser with inner sides of the discharge tube walls coated by discontinuous gold film to reduce the degree of disassociation of CO_2 molecules. The gold film at walls was used to acts as catalyst to reform the decomposed CO_2. The gold was found to exhibits detectable catalytic action only in the presence of the discharge. With distributed gold film both sealed-off and flowing gas CO_2 lasers achieved 122 W/m output power. Therefore the output power of the laser was increased by 93 percent in case of sealed-off CO_2 laser and 47 percent in case of flowing gas CO_2 laser than identical laser without gold catalyst. The catalytic activity of the gold was found to decrease with the temperature.

Tripathi et al. [9] reported that that if the temperature of the "Au(5 atom %)/ Fe_2O_3" catalyst is maintained to an optimized value then the absorption of the CO_2 is prevented in the bulk of the catalyst and result in a required level of CO oxidation activity. An outer jacket with inner walls coated with the "Au(5 atom %)/ Fe_2O_3" catalyst was used. The arrangement was made such so as to expose the gas mixture to catalyst surface, which in turn responsible for the recombination of the dissociation products. The performance of the laser was compared with the one without catalyst. Both of the lasers were operated with interruptions during nighttime and during weekends. It was found that the output power of the laser without catalyst dropped to zero in 17 days. While the initial output power of the laser with catalyst was found steady even after five months of operation.

According to Knapp [10] the use of silver-copper material for the cathode design reduces the gas consumption by sputter pumping through chemisorption and physisorption. The laser tube was constructed of Pyrex, fabricated on the Boulder Campus by the Master Glass Blower. The design was made to incorporate a laser bore nested in a water cooling jacket, with a feed through the water jacket so that the discharge can go to an external cathode and anode. The external electrodes lower than the axis of the laser tube bore were used to reduce the possibility that sputtering or oxidation products at the electrodes will contaminate the optics.

Nevdakh [11] optimised the output power of a sealed-off tunable cw CO_2. The dependences of the small-signal gain for the 10*P*(20) line and of the output powers for different transmittances of the cavity on the discharge current were determined. The distributed loss coefficient and the saturation parameter were measured. The saturation parameter increased continuously with increase in the discharge current, leading to a mismatch between the output power and gain maxima. It was established that the principal factor limiting the output power of cw electric-discharge CO_2 lasers is not an increase in the temperature of the active medium but the dissociation of CO_2